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ABSTRACT

Coelophysis was an ostrich-like, meat-eating dinosaur that inhabited southwestern New York State approximately 200 million years ago. At that time the region was semi-tropical and hosted a bizarre array of amphibians, reptiles, and plants while experiencing unrest in the form of basin settling, earthquakes, faults, and intrusions and outpourings of lava. Presented in this document are descriptions of (1) the geologic history of New York before and after Coelophysis; (2) the morphology, behavior, and habitat of the dinosaur; and (3) the rocks in the New York basin during Coelophysis' time. A bibliography and list of some museums where dinosaur fossils and/or restorations may be seen are also provided. (Author/JN)

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Circular 49

Geological Survey

December, 1981

THE WORLD OF COELOPHYSIS –
A New York Dinosaur of
200 Million Years Ago

by DONALD W. FISHER
State Paleontologist

Coelophysis, "king" of the predatory
dinosaurs during Late Triassic-Early
Jurassic time in eastern North America.
(Drawing by Kathryn M. Conway)

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Figure 1. *Coelophysis*, "king" of the predatory dinosaurs during Late Triassic-Early Jurassic time in eastern North America.



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Figure 2. Life-size replica (1.5m $\approx$ 4.7 ft high; 2.7 m $\approx$ 9 ft long) of the carnivorous dinosaur *Coelophysis*. Model by Louis Paul Jonas Studios, Inc., Hudson, N.Y. and property of the New York State Museum, Albany, N.Y.

THE WORLD OF *COELOPHYSIS* – A New York Dinosaur of 200 Million Years Ago

by Donald W. Fisher, State Paleontologist

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Museum

ABSTRACT

Coelophysis was an ostrich-like, meat-eating dinosaur that scurried about, leaving crisscrossing trackways on mud flats, in southeastern New York State about 200 million years ago. At that time the region was semi-tropical and hosted a bizarre array of amphibians, reptiles, and plants while experiencing crustal unrest in the form of basin settling, earthquakes, faults, and intrusions and outpourings of lava. This upsetting activity accompanied the split of a previously welded "continent" (tectonic plate), giving birth to separate North American and Afro-Eurasian plates and the still-spreading Atlantic Ocean in between.

HISTORICAL BACKGROUND

Since the beginning of the 19th century, dinosaur footprints have been known from the neighboring states of Connecticut, Massachusetts, and New Jersey. Apparently the first to have recorded the existence of these trace fossils in the Connecticut River Valley was Pliny Moody, a student at Williams College, who, in 1800, regarded them as tracks made by Noah's raven. This interpretation was compatible with the thought of that day, for most rock markings attributable to prehistoric animals were viewed as resulting from the Noachian Flood of the Bible — an archaic and paleontologically implausible opinion still held by some nonscientists. These Connecticut Valley footprints were among the first relicts of ancient animals to attract the attention of the early 19th century American geologists, one of whom was the eminent Professor Edward Hitchcock (1793–1864), President of Amherst College and State Geologist of Massachusetts (Figure 3). The prevalence of footprints in the red sandstones of Amherst's "backyard" — the Connecticut River Valley — encouraged Hitchcock to become the first serious investigator of these fossils — which he regarded as bird tracks. During the summer of 1835, Hitchcock zealously scrutinized the Connecticut Valley countryside examining natural and artificial rock exposures for his supposed "bird" tracks. That successful summer's work provided the material for *Ornithichnology — description of the footmarks of birds (Ornithichnites) on New Red Sandstone in Massachusetts* (1836), — the pioneer work on dinosaur footprints in North America! Hitchcock pursued his research on these fossils for many years afterward, culminating in the *Ichthyology of New England* . . . (1858, and its supplement 1865) but to his dying day he was unaware that he was describing footprints of dinosaurs rather than those of large ground birds. In 1861, a momentous discovery of the first skeleton (with feather impressions) of the ancestral bird *Archaeopteryx*, from the Late Jurassic limestones at Solnhofen, Germany demonstrated that birds had not evolved from their reptilian ancestors until after the end of Triassic time and that, therefore, the plethora of 3-digitated footprints of the Connecticut Valley were, in reality, those of bipedal reptiles. Since Hitchcock's day much has been learned about Triassic-Jurassic rocks and fossils (including the discovery of dinosaur bones), paleoecology, plate tectonics, sedimentology, polar wandering, isotopic age-dating, etc. and the application of these studies to such Triassic-Jurassic basins as the Hartford Basin of the Connecticut River Valley and the Newark Basin of southeastern New York and New Jersey. Nevertheless, there is much yet to be learned. Like Schubert's Unfinished Symphony of Music, paleontology will always be an "Unfinished Symphony" of science.

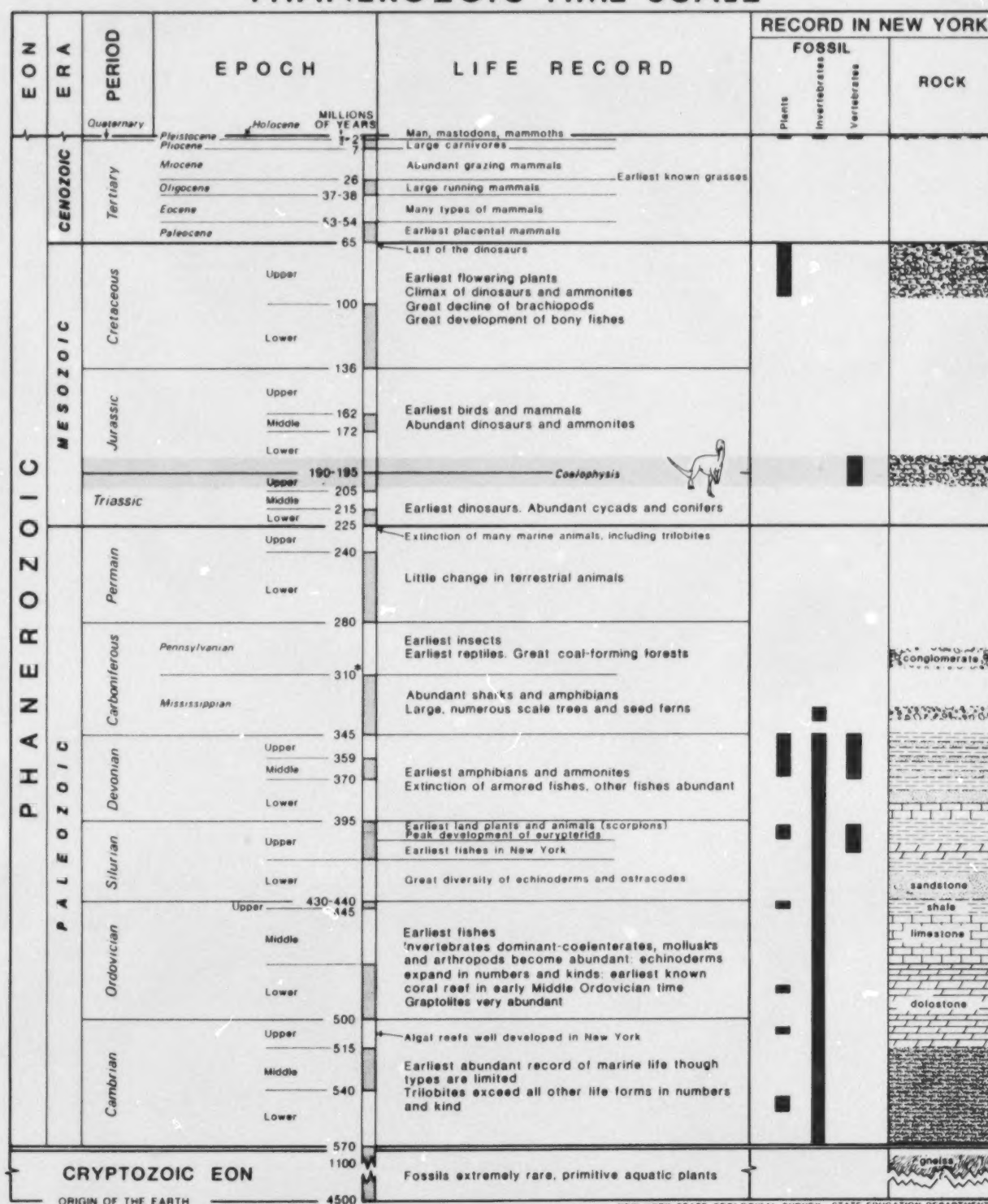


Figure 3. Edward Hitchcock, Professor of Geology, Amherst College, Amherst, Massachusetts (1825–1864); first serious investigator of dinosaur footprints in eastern North America.

Until 1972, no fossils of dinosaurs were known from New York State. Now, thanks to the sharp eyes and generosity of two students, Paul Olsen and Robert Salvia, the New York State Museum is the possessor of two slabs of rock with bonafide dinosaur footprints. The discovery site is near Nyack, Rockland County, New York where the trackways occur in purplish-red silty mudstone and argillaceous sandstone of the Brunswick Formation of the Newark Group. Radiometric dating (Erickson and Kulp, 1961), using potassium-argon isotopes, of a volcanic body (the Palisades Diabase) within the Newark Group gives an age of origination at 195 ± 5 million years ago, — approximately at the boundary of the Triassic and Jurassic periods of time (Figure 4).

Scientific study of dinosaur fossils from throughout the world demonstrate that these bizarre animals were exceedingly abundant and diverse in form, living habits, and habitats. Stratigraphic and chronologic evi-

PHANEROZOIC TIME SCALE



DATES (except *) FROM Quarterly Jour. Geol. Soc. London, v. 120, p. 260-262 (1964)

NEW YORK STATE GEOLOGICAL SURVEY, STATE EDUCATION DEPARTMENT
Compilation, Donald Fisher Graphics, John Satta 1/81

Figure 4. World Phanerozoic Time Scale. Note especially the position of the Newark Group of rocks of Late Triassic-Early Jurassic age.

dence from dinosaur-bearing strata shows that these creatures lived between 225 and 65 million years ago. However, the numbers of fossils found record only a small percentage of the actual numbers that lived. The chances of unearthing direct clues to their existence (skeletons) or indirect clues (footprints, tail-drag markings, coprolites or fossil excrement) are quite remote. Ideally, a relatively catastrophic death with immediate burial is necessary for fossilization to occur. Realistically, however, when most animals die, their remains are scattered by scavengers or chemically and mechanically reduced or obliterated by the elements. One has only to observe how the remains of dead wild animals are gnawed by rodents and disintegrate through storm and chemical actions; very rarely are they preserved by accidental burial. The rare fortunate discovery of these fossil footprints in New York indicate that the animals which made them were once

probably common here. Paleontologists (scientists who study fossils) have concluded that the creature that made these footprints was the dinosaur *Coelophysis* (see-low-fy-sis), which name refers to its hollow bones. To date, no bones have been found in New York. Our identification is supported by the finding of rather complete skeletons associated with footprints (Colbert, 1972) identical to those from New York State and in the same age strata — the Chinle redbeds — at Ghost Ranch, near Abiquiu, northwestern New Mexico. It is interesting to note that the pioneer American paleontologist Edward Drinker Cope (equally famous for his feuds with contemporary paleontologist Othniel Charles Marsh) first described *Coelophysis* in 1887 from skeletons discovered near Cerro Blanco, several miles west of Ghost Ranch and in the same Chinle Formation.

NEW YORK BEFORE *COELOPHYSIS*

As background for an impression of *Coelophysis* (= *Podokesaurus*) world, it is helpful to briefly review the geologic history of our region prior to *Coelophysis* time. The area now occupied by New York State had differing positions and differing configurations on the North American tectonic plate — one of about 15 plates of the upper crust of the Earth that move about ("float") on the "taffy-like" lower crust. The crust rests on an outer core of molten iron and nickel which rests, in turn, on a solid metallic core of iron and nickel. The tectonic plates may move away from one another, producing ocean spreading, or move toward one another, eventually causing continents to collide, override, or underide one another, crumpling the edges of the plates and creating folded mountain chains. For over 300 million years, during the portion of the Phanerozoic Eon known as the Paleozoic Era, the area now known as New York State was alternately flooded and emergent. Oceans advanced over the land during the Late Cambrian (kam-bree-an) and Ordovician (or-doe-vish-an) Periods (Figure 4), bringing with them hosts of invertebrate (backboneless) animals, including sponges, corals, bryozoans, brachiopods, clams, snails, cephalopods, starfish, crinoids, ostracodes, and the now extinct blastoids, cystoids, eurypterids, trilobites.

These invertebrates continued to flourish in Silurian (sy-lure-eean) and Devonian (dev-own-eean) seas in the New York State area. Vertebrate (backboned) animals, in the form of primitive armored placoderm fish, are first known in New York from rocks (Vernon Shale) formed during the Late Silurian Period. These armored and early bony-fishes, together with the early sharks, diversified and increased during the Devonian Period. Likewise, the oldest vascular land plants known from New York State occur in the Late Silurian Bertie Formation. The Empire State is famous for the earliest known fossil forest, of tree-size seed ferns (extinct) near Gilboa in the Schoharie Valley, in the late Middle Devonian Hamilton Group. Thus, our New York State rock record of the environment existent during Ordovician, Silurian, and Devonian ages is especially well documented and well studied (see Figure 4). By contrast, our post-Devonian record of geologic time is scanty. The missing chapters in our book of geologic history are obtained from complete rock sequences of those ages established in other parts of North America.

The rocks of eastern New York are products of a multitude of ancient environments ranging from tranquil seas on stable continental shelves to murky seas

on shaky continental slopes, from expansive deltas to local braided streams, from those affected by violent volcanism to chilling glaciation, from deep burial where rocks behave plastically to shallow burial where brittle rocks fracture easily. During Middle and Late Ordovician time (450–435 million years ago), the ancestral Taconic Mountains were created by a marked uplift along the present trend of the Green and Berkshire Mountains, accompanied by extensive compression owing to the closing together of the American and African-European plates. This produced considerable deformation of the previously undeformed Cambrian and Ordovician strata in the form of westwardly overturned folds and westward moving thrust faults. Furthermore, large areas of rock were transported westwardly, some by gravity sliding into an elongate basin, on the site of the present Champlain-Hudson Valleys, in which thick black mud was accumulating and some by squeezing of rock strata to such a degree that earlier eastern-formed rocks were thrust over later western-formed rocks. In the former gravity-slide case, the resultant heterogeneous mixture of varied types and sizes of rocks, like plums-in-a-pudding, created a unique type of deposit known as *mélange*, *wildflysch*, or *chaos* — a rather diagnostic rock type in eastern New York.

Throughout the ensuing Silurian Period (435 to 400 million years ago) the Taconic Mountains were being vigorously eroded causing thick and varied detritus to be deposited westward in a shallow epeiric sea — similar to Hudson Bay. For a time, salt and gypsum accumulated in super-salty seas. During Early Devonian time (400 to 380 million years ago) extensive layers of limestones, with coral reefs, were formed in shallow, clear, warm water. But this quiescence was short-lived and a renewed mountain-making episode followed (about 370–350 million years ago) which affected much of New England and easternmost New

York — the Acadian Orogeny. The erosional products from this newly uplifted land settled, during Middle and Late Devonian times, in shallow seas to the west as sediments of an expansive and thick delta (Catskill Delta). Now the horizontal rocks of the Catskill Mountains, these strata were first uplifted as a plateau and then dissected into “mountains” during the late Mesozoic and Cenozoic Eras.

During the Carboniferous and Permian Periods of the Paleozoic Era (Figure 4), another mountain-making episode (Alleghenian Orogeny) folded the entire region from Newfoundland to Alabama and brought the Appalachian Mountains to their culmination about 275 to 250 million years ago. The Paleozoic Ocean (Iapetus), that had separated the North American and African-European continents closed and these tectonic plates were welded together once again.

During Early Mesozoic (Triassic) time tensional stresses now developed that ruptured the new single plate and a new ocean (Atlantic) began to spread about 200 million years ago. Basins bounded by lengthy fractures (normal faults) developed in eastern North America from Nova Scotia to North Carolina — an area geologically similar to the modern basin and range area of Nevada. These downdropped basins (rifts or graben) received great quantities of erosional detritus from adjacent uplands. Sediment accumulated above sea level within these sinking basins to thicknesses of up to 4 km (≈ 2.5 miles). The sinking proceeded at a rate of 215–325 mm/1,000 years and endured for an episode of 18 to 23 million years. Throughout this tensional event of the crust (Palisadian Taphrogeny), the floors of the discrete basins remained above sea level, although most such basins did indeed contain lakes, prairies, and swamps. It was under these conditions and at this period in geologic history that the dinosaur *Coelophysis* appeared, flourished, and disappeared.

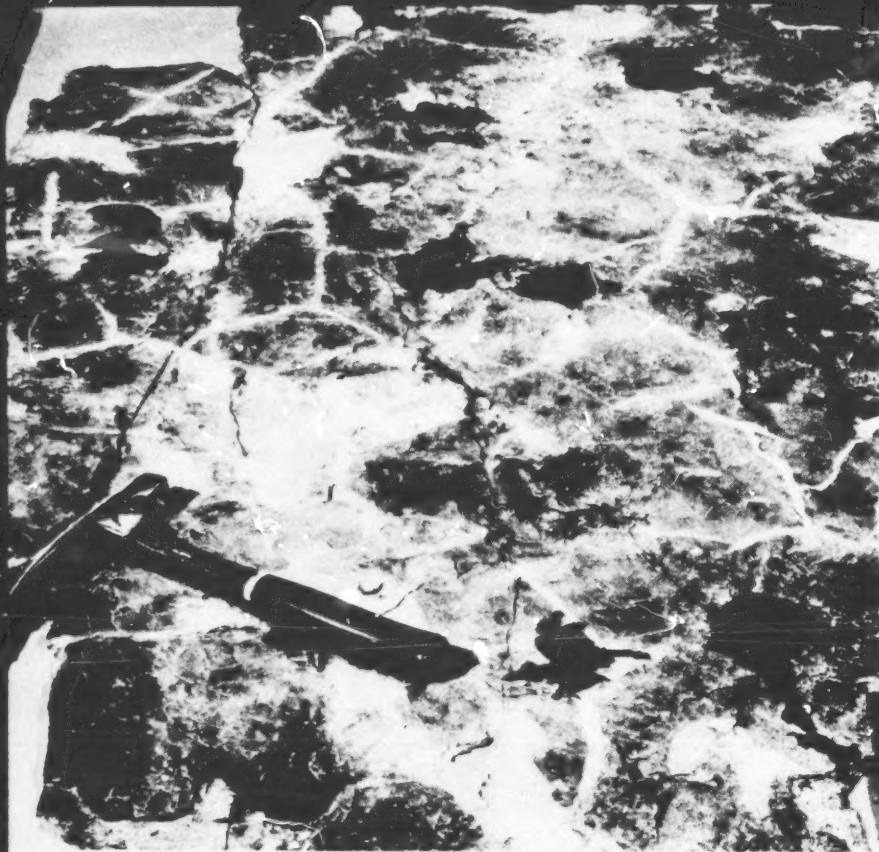


Figure 5.

Trackways of footprints (named *Grallator*) of the dinosaur *Coelophysis*. Specimen collected near Nyack, Rockland County, New York from the Brunswick Formation of the Newark Group of Triassic-Jurassic age. This specimen is the property of the New York State Museum, Albany, N.Y.

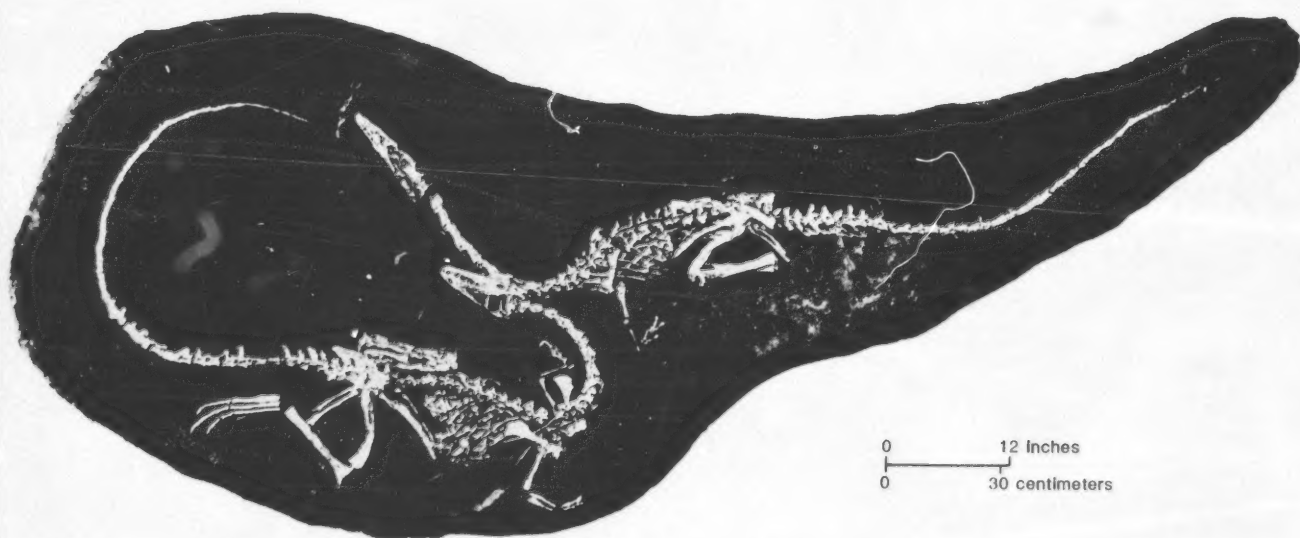


Figure 6. Two essentially complete skeletons of the Late Triassic dinosaur *Coelophysis*, Chinle Formation, northwestern New Mexico (Courtesy, American Museum of Natural History, New York, N.Y.).

COELOPHYSIS—ITS MORPHOLOGY, BEHAVIOR, AND HABITAT

Coelophysis was a slender, bipedal, ostrich-like animal, standing about 1.5 m ($\approx$ 4.7 feet) high and almost 2.7 m ($\approx$ 9 feet) long when fully matured. The depths of footmark impressions and the size of the complete hollow-boned skeletons suggest that the adult animal weighed between 100 and 125 pounds. On the slab in the New York State Museum (Figure 5) the three-toed (tridactyl) bird-like footprints represent at least two crossing trackways. One reveals footprints 13 cm long on the left foot and 12 cm long on the right foot — not an unusual anomaly among walking animals; the strides measure 49 to 51 cm. The other trackway has footprints 14 to 15 cm long and with more erratic strides. It is fainter and deteriorated, due to weathering. Both trackways are referable to the name *Grallator*, given over a century ago when the tracks were assumed to be footprints of giant groundbirds. Over the years, paleontologists have been able to match some of these differently named footprints with skeletons of the animals who made them. However, many footprints still remain unassigned to their animal makers. Dr. Edwin H. Colbert, a paleontologist noted for his research on fossil reptiles, has concluded (1970) that the footprints assigned to *Grallator* and to the *Coelophysis* skeleton (Figure 6) both indeed belonged to the same animal. Direct fossil evidence takes precedence over indirect evidence and, thus, for this animal, the name *Coelophysis* should be perpetuated, and the name *Grallator* abandoned. No single footprint-bearing bed can be traced far laterally. They are cut off by coarse deposits which are fillings of channels made during torrential floodings.

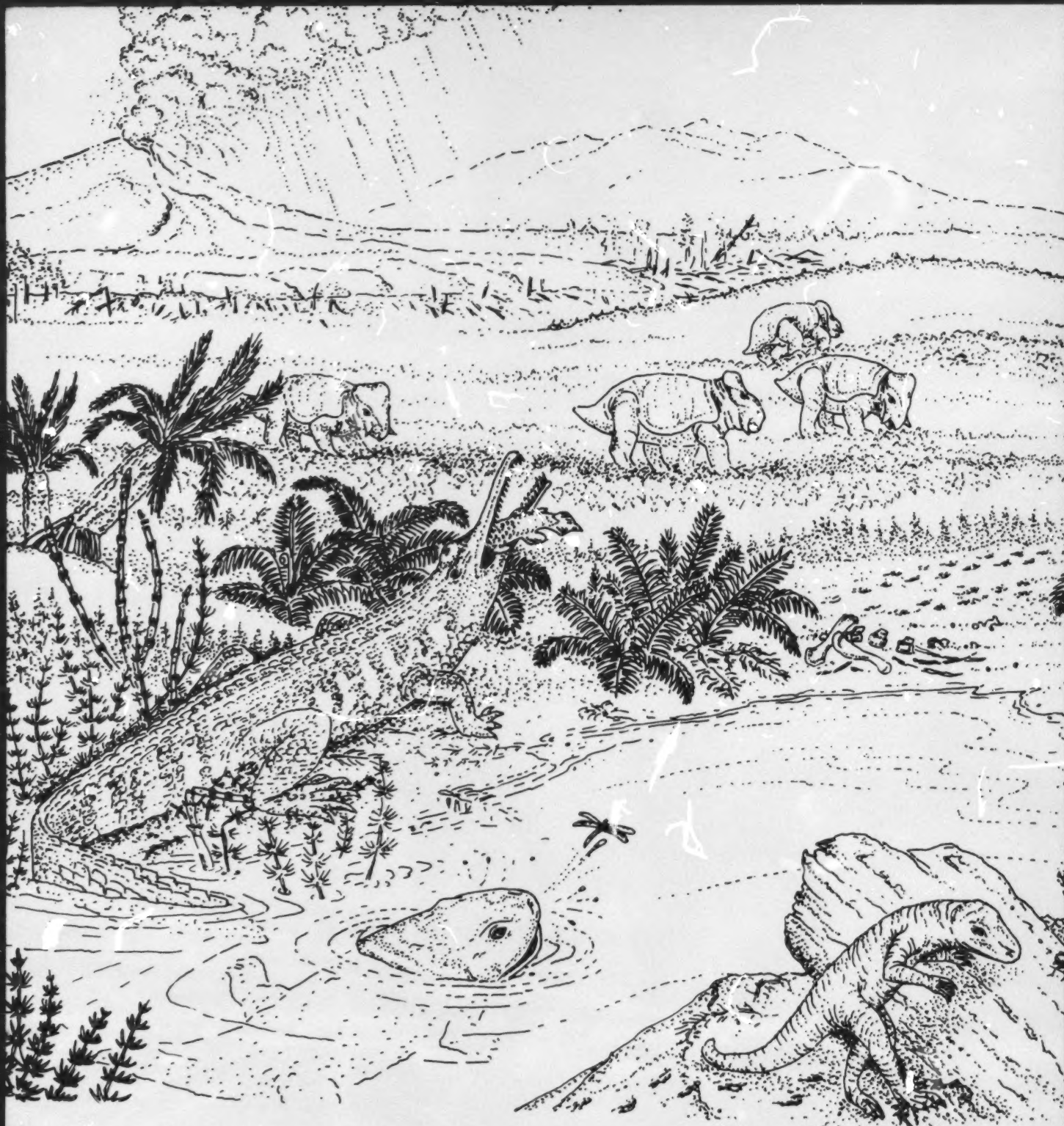
All available evidence points to the fact that *Coelophysis* was an agile, upright, successful predator — among the earliest of carnivorous dinosaurs and perhaps the most successful one of its time. Like many meat eaters the unsuccessful or less efficient-hunting *Coelophysis* individuals may have had to resort to carrion in order to sustain themselves. *Coelophysis* frequently hunted on expansive mudflats, shores of lakes and rivers, selecting those creatures who became "stuck-in-the-mud" or were too slow to escape the accurate thrusts of its powerful flexible neck and ripping teeth. Its hollow bones, streamlined slender body, and sinewy long legs were optimum adaptations for quick pursuit. Furthermore, the animal was well balanced with its pivotal bipedal posture and long, muscular counter-weighted tail. Because no fossil tail-drag markings of *Coelophysis* are known, we conclude that the tail was held off the ground. Small forelimbs with elongated sharp recurved claws were particularly effective in tearing and ripping the flesh of the unfortunate

prey. *Coelophysis*' bird-like head possessed an elongated snout with a relatively large mouth armed with numerous sharp knife-like teeth designed for slashing and severing flesh. Associated fossil remains tell us that *Coelophysis*' choicest food were small amphibians and other smaller plant- and meat-eating reptiles; there is even evidence that *Coelophysis* was cannibalistic! At the aforementioned Ghost Ranch site, bones of a young *Coelophysis* were located within the body cavity of a large *Coelophysis* skeleton. From this relationship one might assume that, rather than laying eggs, *Coelophysis* gave live birth to its young. But the pelvic opening is too small for this to have occurred. The inevitable conclusion is that *Coelophysis* was, occasionally, a part-time cannibal. This is true for modern reptiles.

Truly, *Coelophysis*' body was well-designed and extraordinarily endowed with efficient equipment to satisfy its apparent voracious meat-craving appetite and rapine lifestyle. Unquestionably, it must have been the most feared and most efficient land predator of the Late Triassic-Early Jurassic Newark Basin. Whether *Coelophysis* was a solitary or pack hunter is uncertain. Large numbers of nicely articulated skeletons unearthed at Ghost Ranch, New Mexico tend to favor the view that these animals may have travelled in a herd. But this occurrence may depict a panic situation in which a frightened horde experienced entrapment in a quagmire or quicksand and perished. Whatever the hunting technique, imagine the tumult created by the instantaneity, rapacity, and efficiency of *Coelophysis*' attack and conquest!

What type of backboned creature was *Coelophysis*? We have already learned that its footprints were for many years thought to be those of birds. During the late 19th century, this avian assignment was abandoned in favor of a reptilian classification. Most 20th century paleontologists have traditionally classed *Coelophysis* as a primitive dinosaur, hence a reptile. But within the past few years a review of skeletal microstructure and functional anatomy, made possible by more sophisticated laboratory equipment and procedures, has suggested to some paleontologists that many, if not all, dinosaurs, including *Coelophysis*, differed from the rest of the reptiles in probably being warm-blooded like the mammals. Except for those who believe that modern birds are "the dinosaurs of today" we may dismiss the bird assignment for no fossil feathers or feather impressions have been discovered with dinosaur bones.

In analyzing a prospective animal classification, some remarks about dinosaurs may be appropriate. Dinosaurs varied in size from creatures 25 cm (10 in.)



Near side of river { labyrinthodont amphibian
(*Metoposaurus*)

dragonfly
(*Mormolucoides*)

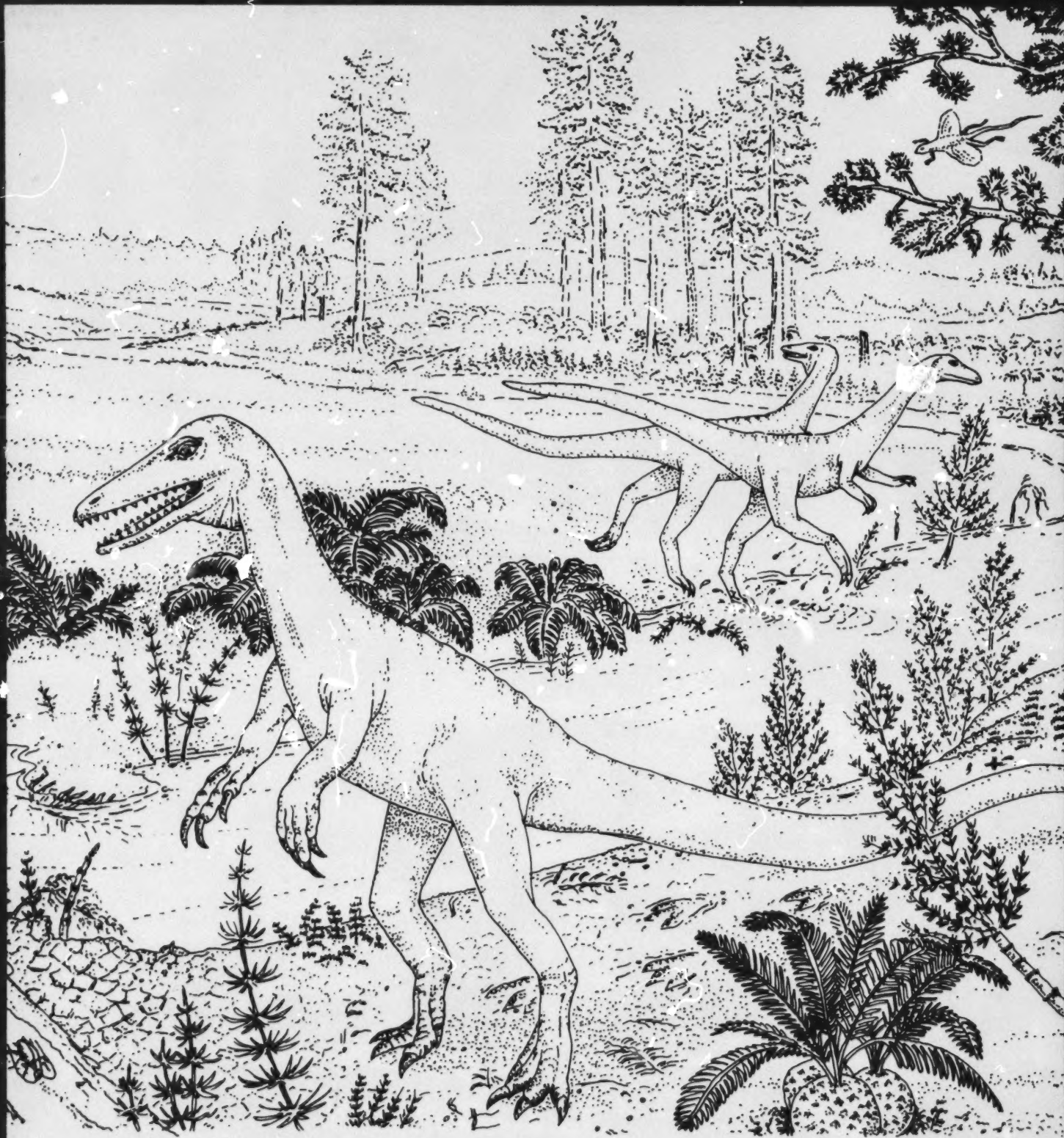
thecodont dinosaur
(*Hesperosuchus*)

Far side of river { crocodile-like phytosaur
(*Phytosaurus*)

coelacanthid fish
(*Diplurus*)

tuber-eating
dicynodont reptile
(*Placerias*)

FIGURE 7. ₁₆ THE WORLD



cockroach

horsetail
(*Equisetum*)

saurischian dinosaur
(*Coelophysis*)

footprints of
Coelophysis (*Grallator*)

cycad
(*Cycadeoidea*)

primitive pine
(*Araucarioxylon*)

ground fern
(*Matanidium*)

gliding lizard
(*Icarosaurus*)

OF COELOPHYSIS

long to giants over 24 m (≈ 80 feet) in length and in weight from 750 g (≈ 1.5 lbs.) to 27,000,000 grams, 27,000 kilograms or 27 megagrams (≈ 30 tons). Dinosaurian habits were as varied as their habitats. Some were exclusively primary feeders or plant-eaters (herbivores) deriving their energy from plants which obtained their energy directly from the sun. Others were exclusively secondary feeders or meat-eaters (carnivores), dependent upon other animals for their food supply. Still others had a mixed appetite for both plants and animals (omnivores). Within these broad categories, some possessed quite restricted diets. For example, some may have been exclusively "shell-crackers," feeding solely on mollusks whereas others were solely insect-eaters, fish-eaters, or lily-pad-eaters. While some browsed, others "grazed" on algae, mosses, lichens, or herbs (for this was before the time of grasses). Though some were solitary feeders, others exhibited various degrees of gregariousness and hunted or fed in small family groups, packs, or herds (Ostrom, 1972). Likewise ability for movement varied; some were swift and maneuverable whereas others were prone. Some thrived in wetlands, others in dry areas. Some lived in lowlands, others at higher elevations. Some were burrowers and a few are alleged to have lived in trees! As can be seen, dinosaurs inhabited virtually every land-based ecological niche, and were a highly successful animal type.

As I mentioned previously, the conventional opinion among paleontologists has been that dinosaurs, like modern reptiles, were coldblooded, i.e., they assumed body temperatures identical to that of their surroundings. Their metabolic rates were regarded as low, generating less heat than is needed for muscles to reach maximum performance levels. Thus the idea prevailed that dinosaurs, like modern reptiles, had to do a great deal of "sunbathing" in order to absorb enough heat to function. This mode of life would require *small and infrequent food supplies* and, correspondingly, low metabolic rates.

But within the past decade, several paleontologists specializing in dinosaur study, foremost of whom have been Drs. Ostrom and Bakker of Yale and Johns Hopkins Universities, respectively, have argued that if dinosaurs were to have done the things that they are supposed to have done, their metabolic rates should have been high! This would have necessitated the intake of *large and frequent food supplies* in order to provide and replenish sufficient blood to sustain a cardiovascular system that would support long and vigorous activity. Furthermore, a high blood pressure would be mandatory for blood to reach the elevated head, up to 6 m (≈ 20 feet) from the ground in some "lofty" dinosaurs (Ex. sauropods, ornithopods, carnosaurs) and to maintain the circulatory system of ponderous animals (Ex. sauropods) weighing up to 27 megagrams (≈ 30 tons) that were at least moderately

active. Large, upright active dinosaurs, like the sauropods, theropods, and ornithopods, would have been incapable of prolonged vigorous activity had they been cold-blooded — as are the reptiles we know today.

Other lines of fossil evidence suggest a warm-blooded body for many dinosaurs. Microscopic study of thin-sections of dinosaur bone reveal that the bone was full of blood vessels with an abundance and patterns almost identical to that of modern mammal bones. By contrast, modern reptile bones have very few blood vessels. Study of dinosaur teeth demonstrates that fossil remains of plant-eating dinosaurs far outnumber those of meat-eating dinosaurs. This high herbivore-to-carnivore ratio argues for a warm-blooded construction because cold-blooded carnivores ingest less food and should show a high predator-to-prey ratio in a given community. The close skeletal similarity of many dinosaurs, particularly the coelurosaurian dinosaurs and the gliding reptiles known as pterosaurs, to birds (acknowledged warm-blooded creatures) argues for a similar circulatory system. Some dinosaurs possessed what amounted to a secondary palate which permitted breathing while eating, — a feature possessed by modern mammals and by crocodilians but not by other reptiles. In summary, available direct evidence from skeletal material and indirect evidence of habits favors the view that some dinosaurs (not necessarily all) were warm-blooded and more like mammals than reptiles in their physiological makeup.

What type of environment did *Coelophysis* inhabit (see Figure 7)? What sort of plants adorned the countryside? Who were *Coelophysis*' animal associates? These kinds of questions and the answers to them are interrelated and form the study of paleoecology. During the latest Paleozoic Era (Permian Period) and earliest Mesozoic Era (Triassic Period), thick, iron-rich, soils (laterites) accumulated on lowlands, intervening between uplands, both created by the Appalachian Mountain-building episode. The ubiquitous red color of the Newark Group strata implies considerable weathering of the source areas and deposition in an oxidizing environment and not that these sediments necessarily were formed in a desert environment — as suggested in frequent earlier interpretations. But the prevailing red color, coupled with the occurrence of sun (mud) cracks, raindrop impressions, local pockets of cobbles and boulders, lenses of poorly sorted sands and conglomerates, and cyclicity of carbonaceous plant matter, all imply alternating wet and dry climates in which occasional torrential rains carried sediments from the uplands and spread them as vari-sized and vari-shaped alluvial fans upon the lowlands. Monsoon-like rains, like those of our present-day tropics, created swollen lakes and rivers. By contrast, the alternate rainless drought periods greatly reduced the size of, or obliterated, water bodies, thereby restricting the available living space of aquatic or semi-aquatic

animals and plants. These seasonal variations obviously affected the quantity of available food, population size, area of food availability, and opportunity for predation. These expansions and reductions of community living room ("lebensraum") and food supply governed the numbers and kinds of occupants of the fluctuating ecological niches. By the close of Early Triassic time there was hardly an ecological niche that was unoccupied and higher animals, such as amphibians and reptiles (mammals had not yet evolved), played dominant roles in them all. Marine and fresh waters were resplendent with disparate invertebrate animals and fishes. On the land, ground-and-tree-dwelling reptiles thrived. Minute and ponderous amphibians divided their lives between both media. Although there were no grasses or deciduous (leaf-shedding) trees and no true flowering plants, the verdant plant world (see Figure 7) was amply represented by ferns, mosses, horsetails (*Equisetum*), cycads, ginkgos, conifers (*Araucaria*), and algae — all of which were concentrated along lakes, ponds, and streams. This lush plant life would appear to provide an ample food supply for plant-eaters, even though they may have selectively eaten roots, tubers, stalks, leaves, seeds, or other plant parts. But the demand sometimes in some places exceeded the supply and animal over-population problems developed. The solution for some was to seek "lebensraum" and food elsewhere and so the reptilian invasion of the oceans began in Triassic time giving rise to the ichthyosaurs, plesiosaurs and later mosasaurs.

In general, the climate of the Triassic world was relatively uniform. Much evidence indicates it was tropical and subtropical. Temperate and polar zone faunas are virtually unknown in the Triassic. Amphibians and reptiles are known from Spitzbergen to Antarctica. However, we must be cautious in interpreting evidence from these widely separated discovery sites because tectonic plate movement (continental drift) and magnetic pole wandering have played intervening roles which may have changed their relative positions. From studies of remanent magnetism in Triassic-Jurassic rocks, geologists have determined that for that interval of time the North Magnetic Pole was positioned south of the Arctic Circle in Siberia at approximately 63°N and 108°E. Today, the North Magnetic Pole is in northern Canada, on Bathurst Island at 72°N, 100°W. Magnetic polar wandering is a demonstrable fact. Between 1945 and 1975, the North Magnetic Pole has migrated from Prince of Wales Island to just north of Bathurst Island — a distance of 500 km (300 miles) — in 30 years!

But let's return to the animals that were contemporary with *Coelophysis* (Figure 7). Broad mudflats, kept moist by the near-surface water table, bordering shrunken water bodies, were now forced to accommodate the displaced coelacanthid fish (*Diplurus*) — an

ancestor of the modern coelacanth *Latimeria*. This lobe-finned fish developed the ability to spend increasingly longer periods of time on land, between disappearing water bodies, in order to survive. But adaptation to the land arena may have been counterproductive for now the coelacanth was easy prey to *Coelophysis* and other meat-eaters. Also, these diminishing water bodies forced the crowding of clams (*Unio*) and crustaceans (*Cyzicus*). Elevated positions of former lakeshores and riverbanks are marked by accumulations of fallen and decayed plants. Phytosaurs (*Phytosaurus* or *Rutiodon*), up to 8 m (26 feet) long, crocodile-like in appearance and habit but with nostrils at the top of the skull rather than at the tip of the snout as in modern alligators and crocodiles, lurked in the dense vegetation along the water's edge waiting for unsuspecting victims. Among these unwary targets were chicken-sized dinosaurs, iguana-sized amphibians, and the alligator-sized relatively gigantic but sluggish amphibians, the fish-eating labyrinthodonts — so named because of the complex labyrinthine enamel of their teeth. Should none of these usual morsels become available, phytosaurs would go sculling into the water seeking fish. Next to the coelurosaurs, the phytosaurs were the most voracious and feared Triassic predators in eastern North America. But these two most formidable villains probably seldom met; coelurosaur-phytosaur encounters were probably accidental, only taking place when one bungled into the realm of the other. Coelurosaurs were more mobile and far-ranging in their hunt for game; phytosaurs, like modern alligators, probably were strongly territorial and more aquatic in habit.

Other known inhabitants of *Coelophysis*' world (Figure 7) were a larval dragonfly *Mormolucoides*; chondrosteian fish (*Ptychaspis* and *Redfieldia*); holosteian fish (*Semionotus*); an amphibian (*Metoposuchus*), one of the last of the procolophonid cotylosaurs (*Hypsognathus*) — a clumsy, herbivorous transitional amphibian-reptilian form, 18 inches long, with a flat skull armed on each side with an array of spikes; the lepidosauroid reptile *Rhynchosauroides*; the gliding lizard *Icarosaurus* (the first attempt at aerial locomotion among the vertebrates); the prosauropod dinosaurs *Ammosaurus*, *Anchisaurus* (= *Anchisauripus*), and *Yaleosaurus*; and the aetosaurian thecodonts *Stegomachus* (*Cheirotherium*) and *Stegomus*. These amphibians and small plant- and meat-eating dinosaurs (Ex. *Hesperosuchus*), some of which may have been scavengers, left a profusion of criss-crossing trackways in the soft mudflats. Seemingly, conditions so conducive to preservation of footprints and other sedimentary features were not equally favorable for the preservation of the bones of the animals which made the footprints. Therefore, we have many more kinds of footprints than there have been bones discovered.

Unquestionably, only a small part of what must have been a most diverse and abundant Late Triassic-Early Jurassic population has been preserved in North America.

Earlier I alluded to the fact that *Coelophysis* is extinct, which means that this species is no longer living anywhere on Earth. Why is this so and what are the causes for animal extinctions? There is no simple answer. Extinctions are complex. Many factors interplay to cause the removal of animal types from the Earth. Factors that affect one group may have no or little effect on a coeval group. Thus, whereas temperature change, salinity change, air poisoning through introduction of toxic gases, loss of preferred food, food poisoning, over-predation, excessively long gestation periods, excess ultraviolet radiation generating sterility or lethal doses, singly or in combination, may bring about the demise of one species, genus, family, order, or class, a contemporary species may be eliminated because of other ecological or physiological reasons — or remain unaffected. Some species "disappear" by

evolving into a "new" species. An example of a durable group which has persisted amid the annihilation of many animal types since Jurassic time are the bizarre and conservative turtles. On the other hand, just why phytosaurs suffered extinction whereas their ecological and almost identical successors — the alligators and crocodiles — survived (albeit human effort to reduce their numbers is thereby producing an endangered species) is mysterious! *Coelophysis*' extinction is presently unexplainable. Precisely why the most efficient predator of its time should disappear from the face of the Earth is unknown. A plausible explanation is that the Jurassic Period witnessed a broad development of many types of dinosaurs some of which were larger, more aggressive, more efficient hunters. These competed for the same food in the same ecological niche as *Coelophysis*. It is reasonable to suppose that *Coelophysis*, himself a predator, became victim to these newer, more adaptable and more proficient predators, — just another example of the great game of survival of the fittest.

THE ROCKS OF COELOPHYSIS' TIME

The only relict of *Coelophysis*' physical world in New York State are the rocks of the Newark Basin (see Figures 10, 11) so well displayed in Palisades Interstate Park, dedicated in 1909 as part of the Hudson-Fulton celebration. The park was created so as to save the Palisades from destruction by widespread quarrying. John D. Rockefeller, Jr. was prominent in this salvage. But the history and rock types of the other Triassic-Jurassic basins of eastern North America also furnish critical data to supplement our story. About 200 million years ago, the Newark Basin received sediments, derived from stripping of the covering layers of the adjacent uplands, — the Hudson Highlands to the northwest and a now vanished land to the southeast. Concurrent with this continental sedimentation, vertical movements occurred along a pronounced fracture or normal fault now known as the Ramapo Fault. This 1,100 million year old zone of weakness in the crust marked the northwest boundary of the Newark Basin, and thus created a half-rift or half-graben. The resultant basin, in common with the other Triassic-Jurassic basins, follows the regional grain of the earlier formed Appalachian folds; in New York and New Jersey the basin trend is about N 30°E to N 45°E.

The Newark Group of rocks is divisible into: (Figure 10)

Stockton Formation (lowest and oldest) — well sorted, fine to coarse grained, yellowish-gray to pale orange, thick-bedded, feldspathic sandstone (arkose) and arkosic conglomerate interbedded with reddish-brown and pale lavender, silty and shaly mudstone.

Lockatong Formation (not exposed in New York) — dark gray to black shaly, limy mudstone with thin calcareous and dolomitic laminae. It is regarded as a deposit formed in a relatively large lake. The unit grades northward into the Stockton and Brunswick Formations. The Lockatong is noted for its superb fossils, especially of fish, from the old Granton Quarry near North Bergen, New Jersey.

Brunswick Formation — reddish-brown, shaly mudstone interbedded with red-brown sandstone, grading into coarse grained conglomerate. This **Hammer Creek Conglomerate** has clasts (blocks and boulders) of various older formations, principally limestone and dolostone of the Cambrian-Ordovician Wappinger Group in New York State, some of which are one meter ($\approx$ 3.3 feet) in diameter. The conglomerate is best developed near the western margin of the Newark Basin, adjacent to the Ramapo Fault, and interfingers basinward into the finer Brunswick Formation.

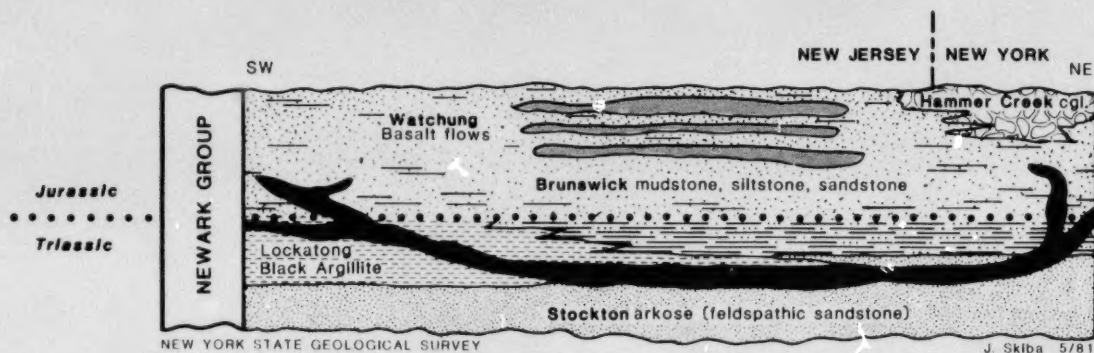


Figure 8. Schematic stratigraphic profile of the Newark Group, showing relationships of its rock units and approximate horizon of Triassic-Jurassic boundary.

Palisades Diabase — an Early Jurassic (195 ± 5 million years old, based on radiometric dating utilizing ratios of isotopes of potassium and argon) sill (parallel to bedding) and dike (transsects bedding) that intruded as molten lava into all units of the Newark Group. More accurately, the diabase is a very low-angle semi-circular dike. The Palisades extends as an east-facing cliff for more than 65 km (≈ 40 miles) along the west bank of the Hudson River from west-central Staten Island to High Tor at Haverstraw, NY. Tor is an old English name for a hill and High Tor was made famous by Maxwell Anderson in his play of the same name set in the 1930's. It creates an impressive wall that, when viewed from the east bank of the river,

gives the appearance of a colonial stockade of vertical logs, hence the name "Palisades" (Figure 9). This columnar fracturing (jointing) was produced by shrinking (tension) when the lava cooled. The cooling diabase created 3-spoked tension cracks that radiate out at 120° from the nuclei or juncture of tension, producing columnar 6-sided polygons. The diabase is medium to dark gray, on fresh fracture, composed principally of the dark-green mineral pyroxene (augite) and the light-gray mineral feldspar (plagioclase) which together give a "salt-and-pepper" effect; olivine and quartz are subsidiary minerals. A marked concentration of olivine 4.5-6 m (15-20 feet) thick occurs about 12-15 m (40-50 feet) above the base.



Figure 9. The Palisades — a lava sill or dike of diabase within the 200 million year-old Newark Group. Note the characteristic vertical columnar jointing due to cooling tension cracks, giving rise to the appearance of a stockade or palisade. (Photo courtesy of Photography Section, N.Y. State Museum).

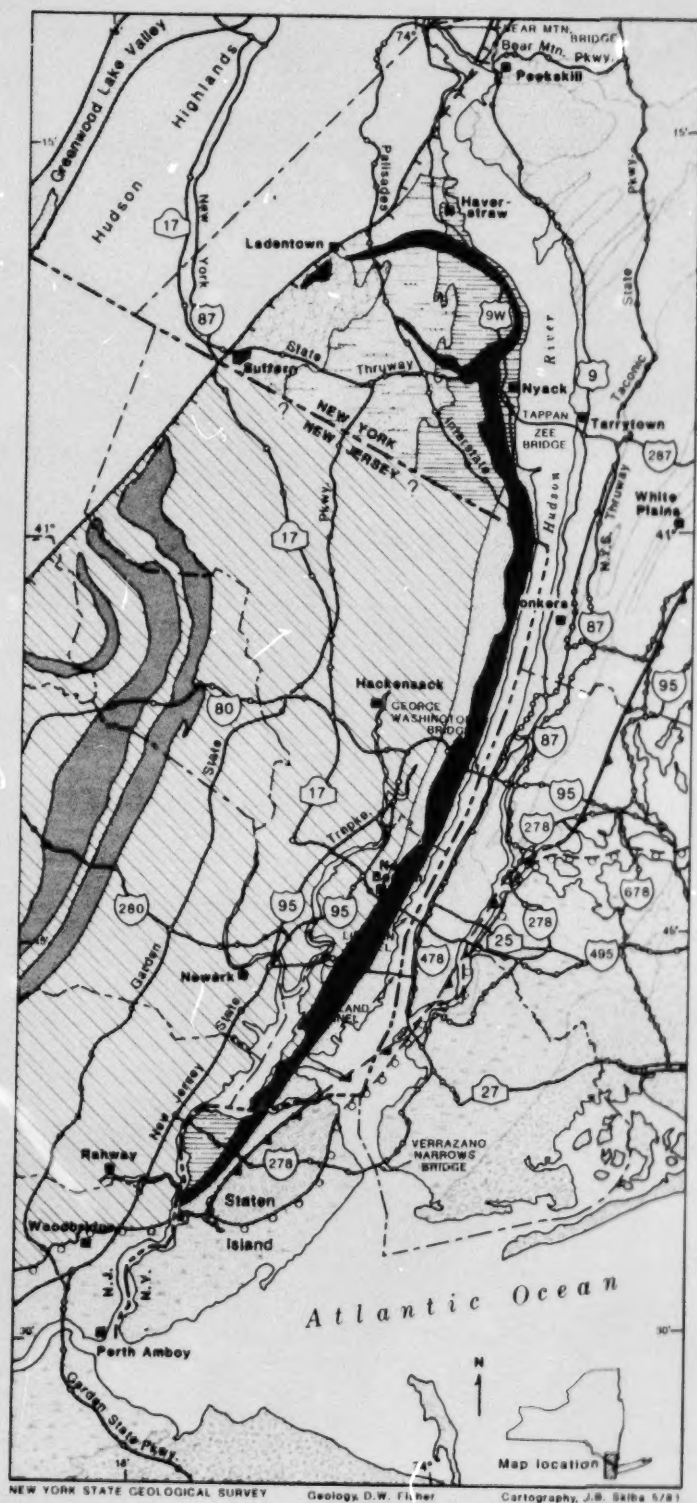
The younger **Watchung Flows** (see Figures 8 and 10) in New Jersey were extruded at the surface and are similar in appearance and formation to the Columbia River basalt flows of the northwestern United States and the present-day lavas of the Hawaiian Islands. Spectacular zeolite mineralization occurs in joints of these nonpillowed flows, mineralized after burial by circulating ground water, perhaps derived from compaction and dewatering of the underlying Brunswick mudstone.

The terms "trap" or "traprock," from the Swedish word *trapp*, meaning stairs, are frequently applied to the Palisades Diabase and similar basaltic rocks. Where columnar jointing is prevalent and where horizontal joints intersect the vertical joints, the vertical columns break down into blocks that resemble giant stairways, hence the name traprock. Some of the brownstone, so abundantly used for home construction in New York City during the 19th century, is traprock that has weathered a brown color although most is feldspathic sandstone (arkose). Because of this durability, diabase (trap) has, in the past, been utilized as paving blocks.

Outcroppings of **Ladentown Trap** (Figure 10), about 3.2 km ($\approx$ 2 miles) by 1.6 km ($\approx$ 1 mile) are separated from the northern terminus of the Palisades Diabase by intervening much younger glacial deposits which conceal the direct relationship between the two. Physically, the Ladentown is somewhat different from the Palisades, being a vesicular basalt with ropy or pa-hoehoe (pa-hoy-hoy) structures similar to the Watchung Flows and to modern Hawaiian lavas. In addition, the Ladentown has curved cooling joints like those of surface lava flows. Conceivably, the Ladentown may represent the portion of the Palisades Diabase which cooled at the surface rather than sandwiched between Newark strata — as is the situation along the Hudson River.

The total thickness of the Newark Group is difficult to ascertain because no complete section is exposed nor has a well or borehole penetrated its entire thickness. Partial well borings show that the strata have a minimum thickness of 610 m ($\approx$ 2,000 feet). Projections based on dip of the strata and composite stratigraphic sections range up to 4,600 m ($\approx$ 15,000 feet). In New York, with the knowledge that 610 m ($\approx$ 2,000 feet) occur below the Palisades and that the Palisades is 305 m ($\approx$ 1,000 feet) thick and that another 610 m ($\approx$ 2,000 feet) plus occur above the Palisades, a reasonable estimate for the thickness of the Newark Group is 2,500 m ($\approx$ 8,200 feet).

The Palisades Diabase, a sill for much of its exposed extent, dips gently westward and exhibits a hooklike shape from Nyack north to Haverstraw (see Figure 8). Here the diabase transects the Brunswick Formation and is dike-like rather than sill-like. Thus, the diabase is younger than the Brunswick Formation, at least in New York. Erickson and Kulp (1961) have determined, from potassium-argon isotope ratios in the mineral biotite in the diabase, that the time of formation of the Palisades Diabase was between 186 to 196 million years ago (the usually published averages are 190, 191, and 195). Fossil pollen evidence from the Upper Brunswick claims an Early Jurassic age on the basis of comparison with corresponding pollen in the type Jurassic of Europe (Cornet, Traverse, and McDonald, 1973). Cornet and Traverse's fossils are from the Hartford Basin in the Connecticut River Valley. Some structural geologists have long advocated that the Newark and Hartford Basins are, in fact, related and that they are the west and east flanks, respectively, of a single broad upfold or anticline. Furthermore, they theorize that the once-intervening redbeds have been eroded. The evidence is compelling though not conclusive. The foregoing reasoning strongly argues for an Early Jurassic age for the Palisades Diabase with the Jurassic-Triassic boundary, at about 200 million years old, lying within the Brunswick Formation.



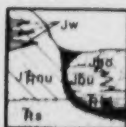
EXPLANATION

Cretaceous

- Magothy, Mattawan, Monmouth, marine gravels, sands, silts, clays (extends to eastern tip of Long Island)
- Raritan continental gravels, sands, clays

POTENTIAL BEARER OF DINOSAUR FOSSILS

Jurassic-Triassic (NEWARK GROUP)



- Jw Watchung Basalt flows
- Jp Palisades Diabase (195 m.y.a.)
- Jnu Newark Group, undifferentiated
- Jhc Hammer Creek Conglomerate
- Jbu Brunswick Formation (upper)
- Rbl Brunswick Formation (lower)
- Rs Stockton Formation

POTENTIAL BEARER OF DINOSAUR FOSSILS

Devonian

- Peekskill Granite (350 m.y.a.) east of Hudson River near Peekskill; Helderberg & Onondaga carbonates with marine invertebrates, Bellville flagstones with plant fossils, Schunemunk Conglomerate at top of section in Greenwood Lake Valley in NW corner of map

Ordovician

- Cortlandt Igneous Complex (434 m.y.a.) norites, peridotites

Ordovician-Cambrian

- Manhattan Schist, Inwood Marble

AFRICAN-EUROPEAN
TECTONIC PLATE

Ordovician

- Staten Island Serpentinite

Ordovician-Cambrian

- Hartland Schist, Harrison & Bedford Gneisses

Proterozoic

- Hudson Highlands gneisses (1,085-1,170 m.y.a.) in north; Fordham Gneiss (1,250-1,300 m.y.a.) & Yonkers Granitic Gneiss (575 m.y.a.) infolded with Ordovician-Cambrian rocks

SYMBOLS

- Faults bordering Greenwood Lake Valley
- Ramapo Fault, hachures on downdropped side
- Cameron's Line, suture between North American tectonic plate on west & African-European plate on east
- Fall line, boundary between sediments of the Atlantic Coastal Plain and older rocks of the Piedmont

- Interstate
- Federal
- State

m.y.a. millions of years ago

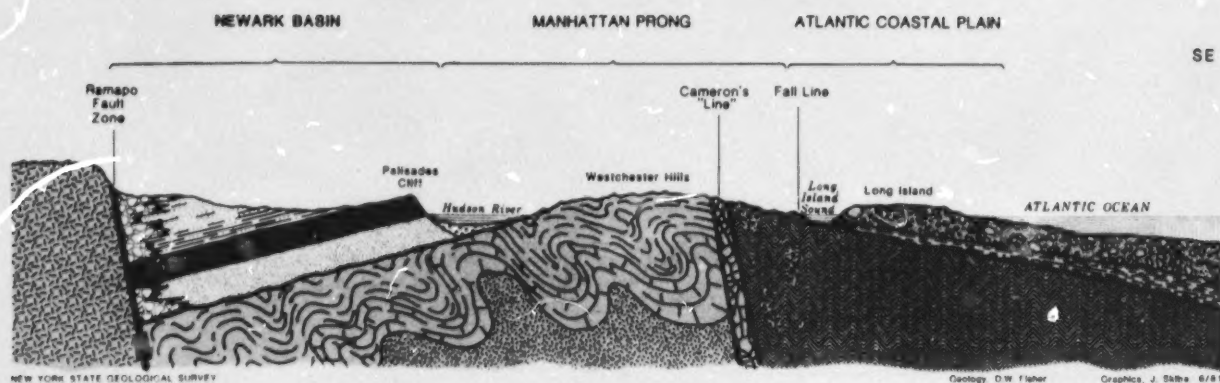
Interchange

State boundary

County boundary

0 5 10 Kilometers
0 5 10 Miles

Figure 10. Generalized geologic map of southeastern New York State showing the potential dinosaur-bearing strata (Newark Group, Raritan Formation) in relation to their adjacent stratigraphic units.



EXPLANATION

ATLANTIC COASTAL PLAIN

SEDIMENTS

- Modern alluvium
- Magothy, Matawan, Monmouth gravels, sands, silts, clays
- Raritan clays, sands

HOLOCENE

CRETACEOUS

NEWARK BASIN

IGNEOUS ROCKS

- Palisades Diabase

SEDIMENTARY ROCKS

- Hammer Creek Conglomerate
- Brunswick & Stockton sandstones, siltstones, mudstones

TRIASSIC-JURASSIC

MANHATTAN PRONG

METAMORPHIC ROCKS

- Harrison & Hartland Gneisses with pods of Serpentine Rocks of African Plate or Island Arc
- Manhattan Schist
- Inwood Marble
- Fordham & Yonkers Gneisses

CAMBRIAN-ORDOVICIAN

HUDSON HIGHLANDS

METAMORPHIC ROCKS

- Hudson Highlands gneisses

PROTEROZOIC

Symbols

- Ramapo Fault Zone, normal fault downdropped on southeast
- Cameron's "Line"

Figure 11. Generalized structure profile across the Newark Basin, from the Hudson Highlands to the Atlantic Ocean.

AFTERMATH OF *COELOPHYSIS*' WORLD

The Palisadian Taphrogeny, an episode of brittle crustal disruption, principally by block faulting, accompanied *Coelophysis*' demise. (In contrast, *orogenies* are compressional mountain-making episodes where plastic deformation, like folding, is prevalent). This tensional event, connected with the initial breakup of previously welded tectonic plates, occurred about 200 million years ago when the present Atlantic Ocean first began widening. This spreading continues today at the rate of 3.5 cm/year or almost 12 feet/century. As best we know, eastern North America stood relatively high during the remainder of Jurassic and Early Cretaceous times (see Figure 4). Long continued erosion, however, wore down the land so that, during Late Cretaceous time the Atlantic Ocean was able to flood the present low-lying coastal plain. A topographic break (the Fall Line) commonly marks the position of the first rapids or falls along a stream as one proceeds upstream from the seacoast. Today, on the Atlantic Coastal Plain, the Fall Line coincides with the present extent of Cretaceous sediments upon the bevelled landscape (see Figure 11). These Late Cretaceous overlapping deposits represent a variety of environments of deposition ranging from deltaic sand, silt, and clay beds of fluvial origin in the Raritan Formation (45-122 m thick) to continental and coastal marine gravel, sand, silt and clay beds of the Magothy, Matawan, and Monmouth Formations (up to 90 m thick in New York State). These sediments accumulated in marshes, lagoons, on coastal beaches, and on the inner continental shelf. Of the Cretaceous formations, only the Raritan clay has yielded dinosaur remains, including the first duckbill dinosaur found in North America, near Woodbridge, New Jersey — just north of Perth Amboy and west of Staten Island. The likelihood of finding additional dinosaur remains in the sparsely-exposed Raritan depends greatly upon new exposures made by natural forces such as storms or artificial ones made by man.

The last notable geologic event to affect southern New York State was a continental glaciation during the Pleistocene Epoch, the last episode of which lasted from more or less some 200,000 to 20,000 years ago. These glaciers, originating in eastern Canada, moved southward, covering the northern part of North

America with a blanket of ice, one to two miles thick, that transported rocks large and small, and both destroyed and constructed landforms as the ice advanced and waned. Pre-existing geologic features were smoothed off or removed and new geologic features were built up. The New York State countryside was markedly changed. Almost all pre-Pleistocene soils were removed and bulldozed in front of and incorporated within the ice. New soils were created by dropping of transported materials, grinding of underlying rock formations, and by deposition in standing melt-water. Obviously, life adapted or changed considerably: many indigenous plants were destroyed; animals, including the now-dominant mammals, were forced to migrate elsewhere so as to continue their existence. Those that failed to do so perished. Following the melting of the thick ice masses, some animals returned to stay for a short while (giant beaver, bison, peccary, giant ground-sloth) while others persisted until today (bear, deer); others took up residence elsewhere (caribou, musk oxen); still others became extinct (mastodon, mammoth). But all of this transpired long after the dinosaurs and *Coelophysis*' world had vanished. Over 60 million years had elapsed between the period of the last dinosaurs (latest Cretaceous) and almost 200 million years elapsed since *Coelophysis*' reign until the gradual cooling led to the bone-chilling climate of the Pleistocene. And to correct a misconception created by the movies and television shows, the last types of living dinosaurs had vanished from the Earth more than 60 million years before paleontologically late-comer humans made their appearance.

Thus, the reader must be careful to keep the time-separate paleontological "worlds" in their proper perspective. The long-ago world of *Coelophysis* was but one of hundreds that have existed on our Earth. With its stormy monsoon-like climate interspersed with hot arid conditions, frequent earthquakes, dislocating faults, outpourings of lava and competitive lifestyles, the world of *Coelophysis* was, indeed, a precarious and shaky existence, not unlike that of much humankind, a world with scenes and actions strange (and yet not so strange) but one much different in appearance to that of southeastern New York today.

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- Thomas, Roger D.K. and Olson, Everett C. (eds.), 1980. A cold look at the Warm-Blooded Dinosaurs (collection of 12 articles by different authors), AAAS Symposium #28, Westview Press, Boulder, Colorado, 514 pgs., few illus.

SOME MUSEUMS WHERE DINOSAUR FOSSILS AND/OR RESTORATIONS MAY BE SEEN

CONNECTICUT

- Yale Peabody Museum, Yale University, New Haven
- (outdoor) Dinosaur State Park, Rocky Hill

COLORADO " and Utah

- Museum of Natural History, Denver
- Dinosaur National Monument

DISTRICT OF COLUMBIA

- National Museum of Natural History (Smithsonian Institution), Washington

ILLINOIS

- Field Museum of Natural History, Chicago

KANSAS

- Museum of Natural History, University of Kansas, Lawrence

MASSACHUSETTS

- Amherst College Museum, Amherst
- Agassiz Museum of Comparative Zoology, Harvard University, Cambridge

NEBRASKA

- State Museum, University of Nebraska, Lincoln

NEW JERSEY

- Princeton University Museum, Princeton

NEW YORK

- American Museum of Natural History, New York City

PENNSYLVANIA

- Carnegie Museum, Pittsburgh

SOUTH DAKOTA

- Museum of Geology, South Dakota School of Mines, Rapid City

TEXAS

- Texas Memorial Museum, University of Texas, Austin

UTAH " and Colorado

- Geology Museum, Brigham Young Univ., Provo
- (outdoor) Dinosaur National Monument, Vernal

CANADA

- National Museum of Canada, Ottawa, Ontario
- Royal Ontario Museum, Toronto, Ontario
- Calgary Museum, Ca'gary, Alberta

Coelophysis

